plates being 6·50 mm. The exposures were made within two or three minutes of one another, to avoid variations due to changes of temperature.

Photographs taken in this way showed that the interference rings are identical for the two lead spectra, and measurements of the diameters of the rings agree within the limits of experimental error, the calculated results showing that there is certainly no difference of wave-length for the line $\lambda = 4058$ as great as 0·003 Å.U. in the spectrum of ordinary lead and of the lead from pitchblende.

In conclusion, I should like to thank Prof. Nicholson for the calculation which he has made for me.

On the Viscosity of the Vapour of Iodine.

By A. O. Rankine, D.Sc., Fellow of and Assistant in the Department of Physics in University College, London.

(Communicated by Prof. A. W. Porter, F.R.S. Received January 15, 1915.)

In a previous communication* I have described the measurements I have made of the viscosity of bromine vapour. The method used for this purpose involved the distillation of bromine from one vessel to another through a capillary tube. The pressure difference between the two ends of the capillary was established by maintaining the two vessels at suitable different temperatures, and the rate of transpiration of the bromine vapour was estimated by observing the volume of the liquid bromine which evaporated in a given time. It was hoped that the same method could be applied to iodine by adjusting the temperatures of evaporation and condensation to values above the melting point of iodine (113° C.), and measuring the transpiration rate by means of the disappearance of liquid from the evaporation vessel.

Preliminary experiments, however, soon revealed the fact that the liquid iodine was not sufficiently mobile, and its surface was too indefinite and variable in shape to allow small changes of volume to be observed. It was, therefore, found necessary to modify in several respects the method used with bromine.

The present paper describes the modified method, which was found to work extremely well and to give very consistent results. Values of the viscosity of gaseous iodine have been obtained at four different temperatures ranging from 124° C. to 247° C.

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* 'Roy. Soc. Proc.,' A, vol. 88, pp. 575–588 (1913).

Description of Apparatus.

The details of the apparatus used are shown in fig. 1, which is not drawn to scale but intended merely to illustrate the principle of the method.

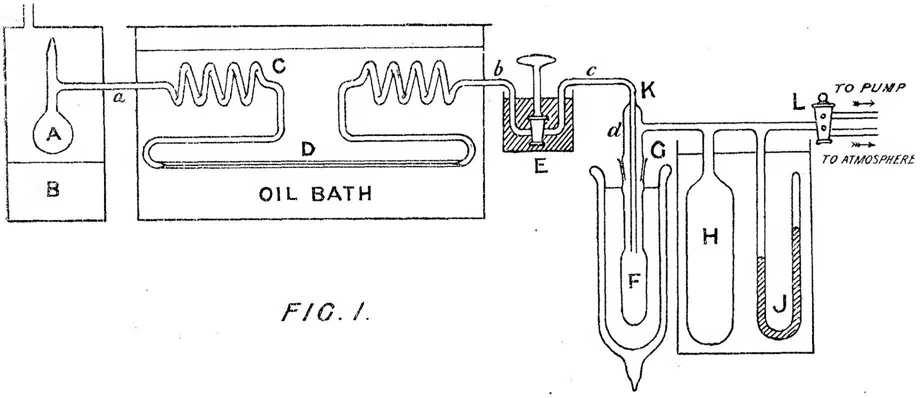

FIG. 1.

The iodine, in a solid state, is contained in the bulb A, which is connected by means of ordinary quill glass tubing to the spiral C, and thence to the straight capillary tube D. The other end of the capillary tube is similarly connected through another spiral to the special tap E, the latter being so arranged that it can be immersed in a bath of mercury. From the other side of the tap the tubing leads to the re-entrant joint K. The outer tube is connected by a conical joint at G to a tube F, which can be removed when desired. The apparatus is further connected, as shown, to the large bulb H, and the mercury gauge J, and finally to the two-way tap L, by means of which the apparatus can be connected to a Toepler pump or the atmosphere; or the tap may be kept closed.

The bulb A is surrounded by a water boiler B so that its temperature may be kept at the temperature of boiling water. An oil bath suitable for temperatures up to 250° C. surrounds the spirals and capillary. The removable tube F is immersed in a freezing mixture contained in a vacuum vessel, and a water-bath surrounds the bulb H and the mercury gauge. Exposed portions of the apparatus, viz., *a*, *b*, *c*, and *d*, are wound with spirals of platinoid wire and well lagged with asbestos paper, so that they can be kept at the desired temperature by passing an electric current through the wire.

Principle of the Method.

The saturation vapour pressure of iodine at 100° C. is equal to 4·48 cm. of mercury. If, therefore, having first evacuated the apparatus, we raise the temperature of the bulb A to 100° C., the iodine vapour will be driven through the capillary tube D and ultimately be condensed in the tube F. (This, however, will only be the case provided that all parts of the apparatus between A and F are maintained at temperatures in excess of 100° C., for otherwise condensation may occur elsewhere than in F.) The pressure in F will be practically zero, for the vapour pressure of iodine at the temperature of the freezing mixture (about $-20°$ C.) is neglibly small. Meyer's transpiration formula is almost certainly not valid in the case where the pressure on one side of the capillary is very small, hence it was deemed necessary to establish a finite and measurable pressure by means of air. The distillation above described would still proceed (although more slowly) if the pressure of air in F is less than the vapour pressure in A. In practice, an air pressure of some 2 cm. of mercury has been used, and this pressure could be measured by means of the gauge J, which is in such a position as to avoid becoming fouled by the iodine.

It will now be seen how the data necessary for the calculation of the viscosity of the iodine vapour can be obtained. The pressure in A is originally the saturation pressure of iodine vapour at the temperature of boiling water at the time of the experiment. Owing to the large surface presented by the iodine—which is solid at 100° C.—it is probable that the vapour maintains its pressure at the saturation value, in spite of the fact that it is being continually removed through the capillary. The pressure on the other side of the capillary is that observed by means of the gauge. By weighing the removable tube F before and after an experiment, the mass of iodine transpired in a given time can be determined. These data, together with the dimensions of the capillary tube, can then be used to calculate the viscosity.

Details of Experiment.

The method of carrying out an experiment was as follows:—

The tube F was first of all accurately weighed and then refitted in position with the freezing mixture surrounding it. With the tap E open, the whole apparatus was then evacuated, the bulb A being meanwhile at atmospheric temperature, at which iodine has a vapour pressure of not more than a small fraction of a millimetre. The tap E was then closed, and dry air was admitted into the part of the apparatus between E and L until the pressure was about 2 cm. of mercury. By immersing the large bulb H in water at ordinary temperature this pressure was kept remarkably steady. An electric current was then switched on through the coils surrounding *a*, *b*, *c*, and *d*, the current being of such a value as to maintain the tubes at about 120° C. The mercury bath surrounding the tap E was also heated to and kept as nearly as possible at this temperature throughout the experiment. It may be mentioned incidentally that though the behaviour of the tap E at this high temperature was expected to give trouble, it was found to work exceedingly well. The tap was lubricated with ordinary black lead to which a small trace of tallow had been added. In these circumstances it was found to be quite gas tight and thoroughly reliable.

The oil bath was heated by means of gas burners to the temperature at which it was desired to measure the viscosity, and the gas supply adjusted until the temperature was steady. A paddle-wheel rotated by means of a motor (not shown in the diagram) was used for continually stirring the oil in the bath. Finally the water in the boiler B was boiled, and the apparatus was then ready for beginning the measurement.

It will be well, at this stage, to consider the conditions of the gases in the various parts of the apparatus. On the left-hand side of the tap E the apparatus contains nothing but iodine. The coolest place is the bulb A, which contains the solid iodine, and the temperature of which is about 100° C. In the apparatus, from A to E, the pressure of the iodine vapour is equal to the saturation pressure at the temperature of A, *i.e.* about 4·5 cm. In the part of the apparatus within the boiler B the vapour is saturated, elsewhere it is superheated, the temperature being considerably higher than the boiling point of water.

On the right-hand side of the tap E there is at first air only, the pressure being about 2 cm. On opening the tap iodine vapour will pass through it, displace the air in C, but rapidly condense in the unheated portion of the apparatus. The flow of vapour through the capillary, and its subsequent condensation in F, continues so long as the tap E is kept open, and provided that the solid iodine evaporates in A rapidly enough to keep the pressure in excess of the air-pressure which has been established in H.

During an experiment the tap E was opened at a definite moment, and left open for a measured time. Meanwhile observations of the pressure in H were taken by means of the gauge, but in none of the experiments could any change be observed. At the end of the experiment E was closed, and air at atmospheric pressure was admitted into the apparatus through L. The tube F was then removed and weighed; whence, by subtracting the previous weight, the mass of iodine condensed in F was determined.

In order to eliminate a small but appreciable error due to the iodine which at the beginning of the experiment filled the tube between the capillary and the tap E, two separate determinations were made, one usually lasting for 10 minutes and the other for 80 minutes. The difference between the two masses condensed in F then gives the amount which had passed through the capillary in 70 minutes.

The question also arises as to whether the pressure in the bulb A retains the saturation value during the progress of the transpiration. This bulb has a considerable volume unoccupied by solid iodine. It therefore contains, previously to opening the tap E, a considerable supply of iodine vapour at the saturation pressure. If, however, after opening the tap, evaporation is not sufficiently rapid to maintain saturation, the pressure would gradually fall, and consequently the rate of transpiration would diminish.

Experiments which extended over various periods of time showed no such diminution, and one may therefore conclude that the powdered iodine supplies a sufficiently large surface to keep the pressure at the saturation value.

Calculation of Results.

As shown in a previous communication,* Meyer's transpiration formula, when transformed so as to apply to mass transpired instead of volume transpired, takes the form—

$$\eta = \frac{\pi \mathrm{R}^4}{16 l} \cdot \frac{(p_1^2 - p_2^2)\, t}{p_0 m} \rho_0 \frac{\mathrm{T}_0}{\mathrm{T}},$$

where η is the coefficient of viscosity, R the radius and l the length of the capillary tube, p_1 and p_2 the pressures of entry and exit, m the mass transpired in time t, ρ_0 the density of the gas at the pressure p_0 and temperature T_0, and T the absolute temperature of the gas during transpiration.

This equation assumes that the vapour behaves like a perfect gas, which, at the high temperatures and under the low pressures of the experiments, is approximately true. The value of ρ_0, the density which iodine vapour would have at the normal temperature and pressure if it behaved like a perfect gas under those conditions, has been calculated from its molecular weight as 0·01133 grm. per $\mathrm{cm.}^3$.

The same capillary tube was used as in bromine measurements and the value of $l/\mathrm{R}^4 = 3{\cdot}763 \times 10^8\ \mathrm{cm.}^{-3}$ at 13° C.

The pressure of entry p_1 is the saturation pressure of iodine vapour at the temperature of boiling water. This was obtained by interpolation from the observations of Ramsay and Young,† the temperature of boiling being calculated from the barometer reading. The values vary from 4·247 cm. at 99° C. to 4·729 cm. at 101° C.

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* 'Roy. Soc. Proc.,' A, vol. 88, p. 580.

† Ramsay and Young, 'Chem. Soc. Journ.,' vol. 49, p. 453 (1886).

The pressure of exit p_2 was observed directly by means of the gauge, subject to the small temperature correction.

Corrections were applied to the approximate value of the viscosity calculated from the above equation, firstly for the variation of the dimensions of the capillary tube with temperature, and secondly for the slipping of the gas over its internal walls. In the first case the coefficient of cubical expansion of glass was taken as 0·00003 and the correction at the highest temperature, 247° C., amounted to 0·7 per cent. The second correction amounts to multiplying the approximate viscosity by the factor $1+4\lambda/R$, where R is the radius of the capillary and λ the mean free path of the gas molecules under the conditions of the experiment. The value of λ, which is only required approximately, was calculated from the approximate value of the viscosity, using the customary formula based on the kinetic theory. At the highest temperature this correction amounted to 2·9 per cent.

The results of the various experiments and the data from which they are calculated are given in the following Table:—

Table I.

Temperature in degrees Centigrade.	p_1 in centimetres of mercury.	p_2 in centimetres of mercury.	Transpiration rate in grm./sec. × 10^5.	Approximate viscosity × 10^4.	Corrected viscosity × 10^4.
124·0	4·538	2·251	6·153	1·801	1·843
124·0	4·473	2·234	5·952	1·801	1·843
170·0	4·546	2·260	5·028	1·979	2·033
170·0	4·435	2·219	4·738	1·990	2·044
205·4	4·388	2·199	4·008	2·131	2·199
205·3	4·530	2·276	4·269	2·129	2·197
247·0	4·524	2·276	3·593	2·318	2·401
247·2	4·562	2·283	3·679	2·310	2·393

The next Table shows the collected mean results, which may be taken as reliable to within one unit in the third significant figure.

Table II.

Temperature.	Viscosity in C.G.S. units × 10^4.
124·0	1·843
170·0	2·038
205·4	2·198
247·1	2·397

Discussion of Results.

The first point of interest in connection with these results is to deduce from them the value of Sutherland's constant C in his equation*

$$\eta = \mathrm{K}\frac{\mathrm{T}^{\frac{1}{2}}}{1+\mathrm{C}/\mathrm{T}},$$

where T is the absolute temperature and K another constant.

If we base the calculation upon the values of the viscosity at the two highest temperatures we obtain $\mathrm{C} = 590$. The reason for excluding the lower temperatures is that Sutherland does not claim that his law is valid for a vapour near the point of saturation. Nevertheless, the value $\mathrm{C} = 590$ gives a calculated value of the viscosity at 170° C. differing very little from the observed value, although at the lowest temperature, at which the vapour was superheated to the extent of 24° C. only, there is a notable difference in the same sense as has previously been shown to exist for bromine.

This is shown in the following Table :—

Table III.

Temperature.	Viscosity observed $\times 10^4$.	Viscosity calculated $\times 10^4$.
124	1 ·84	1 ·80
170	2 ·04	2 ·03
205 ·4	2 ·20	2 ·20
247 ·1	2 ·40	2 ·40

We may now test how far the results for iodine fall into line with the empirical laws which I have shown to hold for bromine and chlorine.

The critical temperature of iodine is 507° C.,† or 780° absolute. The ratio T_c/C is therefore $780/590 = 1{\cdot}32$. This compares with 1·28 for the same ratio in the case of chlorine and 1·25 for bromine. Considering the difficulties of obtaining accurately the critical temperatures of these gases, and also the value of Sutherland's constant C, these three ratios are equal within the accuracy of the experiments.

Further, if we calculate by extrapolation of Sutherland's equation the viscosity of iodine vapour at the critical temperature, we obtain the value $\eta_c = 3{\cdot}58 \times 10^{-4}$, and the value of η_c^2/A, where A is the atomic weight, is $1{\cdot}01 \times 10^{-9}$, which is practically equal to the same ratio for chlorine and bromine.

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* 'Phil. Mag.,' vol. 36, p. 507 (1893).

† From Landolt and Börnstein's Tables.

A consideration of the following Table will show to what degree of accuracy these two empirical laws hold:—

Table IV.

Gas.	T_c/C.	$10^9 \eta_c^2/A$.
Chlorine	1·28	1·02
Bromine	1·25	1·03
Iodine	1·32	1·01

It will be seen that this group of gases in the periodic Table obey laws similar to those which hold for the inert gases.*

A New Type of Series in the Band Spectrum Associated with Helium.

By A. Fowler, F.R.S., Assistant Professor of Physics, Imperial College, South Kensington.

(Received January 19, 1915.)

Introductory.

A previously unknown band spectrum was noticed in the course of experiments on hydrogen and helium made at the Imperial College in 1912, and was further investigated and described by W. E. Curtis in the year following.† An independent account of this spectrum was also given, almost at the same time, by Dr. E. Goldstein.‡ In each case, some hesitation was felt in attributing the new spectrum solely to helium, in consequence of the persistence of traces of hydrogen in the helium tubes employed.

Mr. Curtis found that the band spectrum was best developed, in the wider parts of the tubes, when a discharge with small capacity and a small air-gap was passed through helium at a pressure rather higher than that which is usual in sealed tubes of the gas. The discharge is then quite brilliant, and by giving long exposures, amounting in some cases to seven or eight hours,

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* 'Phil. Mag.,' January, 1911, p. 45.

† 'Roy. Soc. Proc.,' A, vol. 89, p. 146 (1913).

‡ 'Verh. d. Deutsch. Phys. Gesell.,' vol. 15, p. 402 (1913).